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## Rutting in Flexible Pavement: An approach of evaluation with Accelerated Pavement Testing Facility

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### Abstract

Majority of roads in India are constructed of flexible pavements, wherein, the bulk of distress is in the form of either cracking (fatigue) or rutting (permanent deformation). Rutting is the longitudinal depression in the wheel path in bituminous pavements, which can be attributed to excessive consolidation, formed by an accumulation of permanent deformations caused by repeated heavy loads, or lateral movement of the material, caused by shear failure of the bituminous concrete layer, or a combination of both mechanisms. There are countries facing functional constraints on their flexible road pavements due to rutting and trying to resolve this failure. Rutting in pavement is a serious mode of distress beside fatigue in bituminous pavement in high temperature areas including India and may lead to premature failure in pavements and results in early and costly rehabilitation. In addition, rutting in pavements causes hydroplaning, severe physiological and safety concern for users. Premature distress and associated problems in pavement result in an economic burden on tax payer. Hence, this problems needs to be properly addressed through evaluation and mitigation measures so that the occurrence and resulting impacts are minimised.

In order to study the pavement failure modes and to minimise them so as to get good serviceability from the huge road assets the country is having, the actual response of pavement structure needs to be monitored. This necessitates a systematic assessment and performance evaluation of pavement with known design and influencing factors. An array of response measuring instruments, under measurable loading conditions is required to accrue objective indicators. Evaluation strategies use performance monitoring through laboratory and field evaluation, while the field evaluation itself can be accomplished by monitoring in-service pavements or smaller replicate test strips using an 'Accelerated Pavement Testing' protocol.

CSIR-CRRI has recently procured and established a national facility of Accelerated Pavement Testing. Through this, the in-field loading on pavements, and design traffic, tyre pressure can be simulated. A systematic study was initiated on the permanent deformation development involving a flexible pavement designed as per Indian practice. The paper brings out the details of this evaluation study and also features the capabilities and applications of Indian APTF in the issue.

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**Nomenclature**

APT	Accelerated Pavement Testing
HVS	Heavy Vehicle Simulator
MORTH	Ministry of Road Transport & Highways
IRC	Indian Road Congress

**1.0 Introduction**

A rut, whether consolidated (primary) or instability (secondary) is characterized by longitudinal surface depression within the wheel path and may have associated transverse displacement, thereby reducing serviceability and safety of a flexible pavement. Rutting can be the result of permanent reduction in volume (consolidation/traffic densification), permanent movement of the material at constant volume (plastic deformation/shear), or a combination of the two (1). Bituminous concrete is a time, temperature, and stress dependent material, which, when subjected to repeated loading exhibits elastic/ plastic/visco-elastic/ plastic responses. The elastic properties are modeled by modulus of elasticity and Poisson’s ratio since they do not contribute to permanent deformation. Plastic properties contribute to permanent deformation, which is cumulative under repeated loading. There are several factors that influence rutting. Vehicle speed/time and contact pressure are represented directly in the creep rate model, while temperature, asphalt/bitumen mixture characteristics and construction quality are represented in the values of the constants. Shear resistance properties of materials, especially bituminous ones, need to be properly addressed for limiting the rutting. While pavement structural design practices mainly have focused on protecting the subgrade by excessive vertical strain, the shear resistance of the bituminous layers has been left to mixture designers. Adequacy of shear resistance in bituminous mixture is commonly assessed with many methods, such as Marshall Stability, cyclic tri-axial (EN 12697 part 25). There is a conscious effort to shift towards the use of fundamental performance-related test methods.

Two procedures have been used to limit rutting; one to limit the vertical compressive strain on top of the subgrade, the other to limit the total accumulated permanent deformation on the pavement surface based on the properties of each individual layer. In the process, the number of load repetitions  $N_r$  to limit rutting is related to the vertical compressive strain  $\epsilon_z$  on top of the subgrade (Eqn.1).

$$N_r = f_1 \times \left(\frac{1}{\epsilon_z}\right)^{f_2} \dots\dots\dots(1)$$

Several agencies have defined different material constant values for  $f_1$  and  $f_2$ . From the earlier research in India, the rutting model is defined from large number of data for rutting failure of pavements, setting the allowable rut depth as 20 mm, rutting equation is defined and presented (Eqn.2).

$$N_r = 4.1656 \times 10^{-8} \times \left(\frac{1}{\epsilon_z}\right)^{4.5337} \dots\dots\dots(2)$$

$N_r$  = No of Load Repetition in Rutting Failure.

$\epsilon_z$  = the compressive strain on the top of subgrade.

Thus, to find out the number of load repetition to cause rutting failure, the compressive strain at the top of the subgrade is calculated for pavement structure, which has been used in the present study also employing a Mechanistic-Empirical (M-E) design method.

## 2.0 Accelerated Pavement Testing for Rutting Evaluation

Accelerated Pavement Testing (APT) constitutes a vital link between the Pavement Engineering (P-E) tools of laboratory evaluation of pavement materials and the full-scale field behaviour of these materials within a pavement structure. It supports most of the current pavement design methods and forms the basis for developing various theories about pavement behaviour and for this reason, APT has been regarded as a tool which provides pavement engineers the knowledge of understanding of pavement materials and structures in a better way as well as their behaviour under typical traffic loading in a known environmental condition. APT aims to evaluate pavement sections under a range of loading and environmental conditions to improve the knowledge of the potential performance of the pavement layers and structure under a full range of operational conditions. Development of rutting is caused by a combination of densification and shear-related deformation with an increasing number of load applications and may occur in any layer of a pavement structure (2). Hence, the structural design, mixture designs, and pavement construction aim at minimising permanent deformation. As a result, pavement structures are composed of layers possessing required performance properties. These layers attenuate load-induced stresses and limit subgrade stress and deflection. It must, therefore, be ensured that the flexural and shear resistance of the structural layers are good enough to sustain these high stress states.

There are many factors that affect the rutting of the pavements using HVS namely speed, contact pressure, temperature, quality of construction, wandering of the vehicle, layer thickness as per Hani Melhem and Frederick Sheffield (3). Fred Hugo (4) studied that the performance of accelerated pavement testing facility (APTF) with Long term pavement performance (LTPP) studies conducted in especially in South Africa and Australia and reported that the distress pattern of the APTF is similar to the LTPP under the given environmental condition.

### 2.1 APT Facility

In the present evaluation of a flexible pavement, the linear Heavy Vehicle Simulator (HVS) type of APTF has been used. The facility is in operation in the CSIR-CRRI premises in India, and its features are as in Table 1 below.

Table 1: Features of CSIR-CRRI HVS

Feature	Capability
Mobility	Towable over long distances; self-propelled over short distances
Load Application	Static & Dynamic Load Applications
Test Wheel Loads	30-100 Kn
Test Wheel (s)	Single, Super-single, Dual (truck) or Aircraft (Airbus 46×16)
Tyre and load	Single, Super-single, Dual (truck) or Aircraft (Airbus 46×16) (20-200 kN)
Repetitions Per Day	Upto 29000 (Bi-directionally @12.87km/h) ; Upto 14500 (Uni-directionally @12.87km/h)
Trafficked Length	8m (test area length 6m)

Trafficked Width	Upto 1.5 m, depending on wheel configuration
Trafficking Pattern	Variable
Dimensions	Length = 22.8 m ; Width = 3.5 m ; Height = 4.0 m
Total Mass	47000 Kg
Tyre pressure	250 to 850 kPa and tyre temperature 0-80°C
Type of loading	Uni-directional and Bidirectional
Power Source	Diesel (self contained) or electric shore power

### 2.2 Flexible Pavement Test Strip

A flexible pavement section was designed for a design traffic of 30 million standard axles (msa) using Indian Road Congress code entitled “Guidelines for the design of flexible pavements” (IRC:37-2012) of year 2001, with a subgrade CBR of 5%, sub-base of a granular material of thickness 300mm, base of wet mix macadam of 250mm and Dense Bitumen Macadam (DBM) and Dense Bituminous Concrete (DBC) of 160mm and 40mm respectively. The construction of the pavement structure was accomplished incorporating the specifications of Ministry of Road Transport & Highways (MORTH).

### 2.3 APTF Evaluation and Methodology

A loading on dual wheels (11R/22.5) was applied to the APT sections starting at load of 80 kN (half axle) with a tyre pressure of 700 kPa, which is more than the specified standard dual axle load of 80 kN (full axle) and tyre pressure of 560 kPa, to accelerate the damage phenomenon in compressed time period. The HVS is capable of applying load in bi-directional as well as uni-directional traffic. The uni-directional mode of load application was used. The average speed of 10 km/h was selected. The load was applied only during day time. The data for pavement temperature, air temperature, rainfall, humidity was collected regularly using weather station. The test section was divided into 16 segments making it to 8m in length and 900mm width. The initial profile of the section was taken laser profilometer. The profiling of the test section was done at every 5000 passes initially upto 50,000 passes, thereafter at every 10,000 passes for 1, 75,000 and further profile of the section was taken at every 25,000 upto 2,70,000 passes making upto 4.32 msa using fourth power law. The test period was from January 2013-May 2013 during. The Falling Weight Deflectometer (FWD) evaluation was also conducted on the test section at the beginning of the test and the modulus of each layer was calculated using forward calculation given by R.N. Stubstad et. al (2006) (5) at 20 °C temperature of the pavement. The modulus of the bitumen layers were estimated at 35 °C by method given by Young et.al (2011) (6). The modulus of each layer is given in Table 2.

Table 2: Modulus of each layer

AC Stiffness (MPa)		Base Stiffness (MPa)	Subgrade Stiffness (MPa)
Section layers)	Average (bound	Section Average (unbound base)	Section Average (Hogg subgrade model)
1698		258	75.5

In Uni-directional mode of trafficking, in one minute maximum of 9 passes are achieved at the speed of 10km/h. Therefore, one complete pass is taking about 6.67 s for to and fro and loading was in one direction only, therefore, period of loading for one pass is 3.33 s. Rest period is also the same because once the wheel moves upon the test section in forward direction and in reverse direction in lifts and come back to original position.

#### *2.4 APTF Instrumentation*

The APTF instrumentation in used to measure the response of the pavement and also instrumentation were done to measure the temperature using weather station.

##### *2.4.1 Laser Profilometer*

The Profilometer consists of an aluminium frame that spans the cross sectional width of the test section resting on legs on either side of the test section. A measuring head containing the laser head is attached to the beam of the frame via a motorised carriage and moves along the length of the beam taking readings every 10 mm over a total length of 2.56 m. The laser profilometer is shown in Figure 1.



Figure 1: Laser profilometer

##### *2.4.2 Weather Station*

The Davis Instruments weather station (Model type Vantage Pro 2) Includes display console along with Auto-Emptying Rain Bucket, Outdoor Temp and Humidity Sensor, Wind Gauge, and mounting hardware. It gives the data regarding temperature (in °C), relative humidity (in %), barometric pressure (in hPa), daily rain (in mm), rain rate (in mm/hr), wind speed (in m/s) and wind direction. The weather station is shown in figure 2.

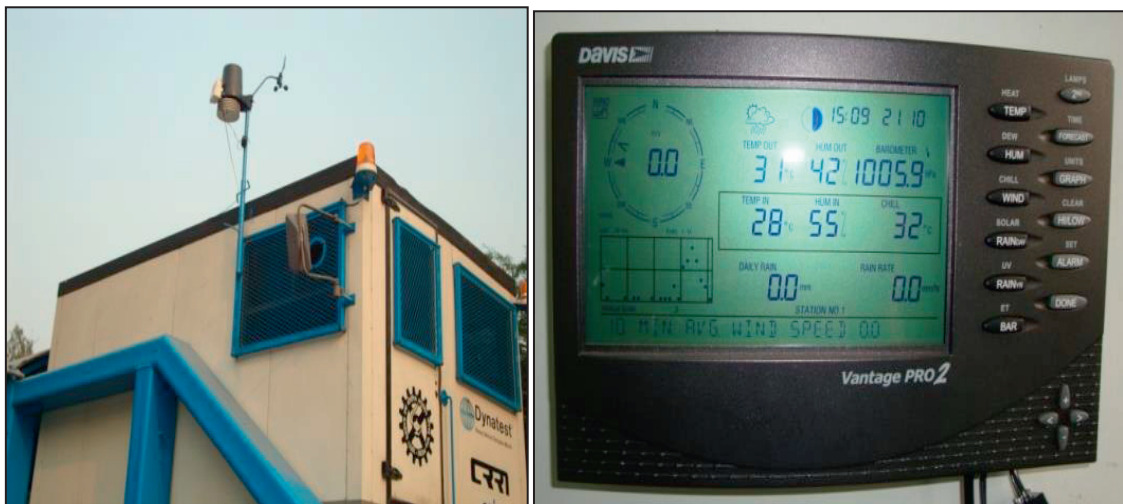


Figure 2 Weather Station Mounted on HVS and Display Console

2.5 Temperature variation during the test period

The pavement temperature was also continuously monitored with a conventional mercury thermometer during the test period from the January to May, 2013 and is shown in figure 3. The surface bottom temperature has been taken at a depth of 50mm from the top of the pavement (surface layer) and same method has been adopted for pavement top temperature.

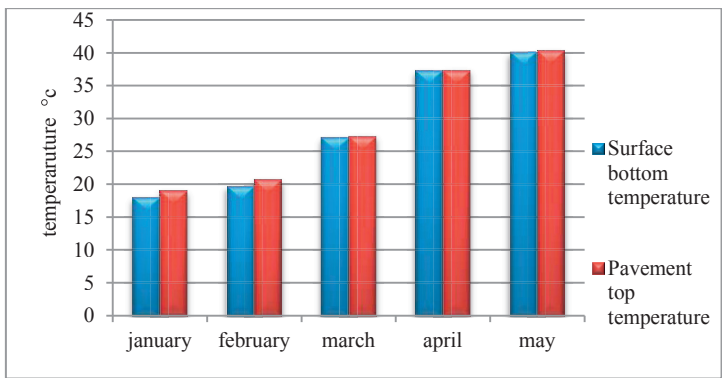


Figure 3: Average temperature variation during test period

### 3.0 Result and Discussion

The rutting gets affected with temperature and moisture condition, the more temperature will cause more rutting, hence rainfall and temperature were measured with weather station installed on top of HVS.

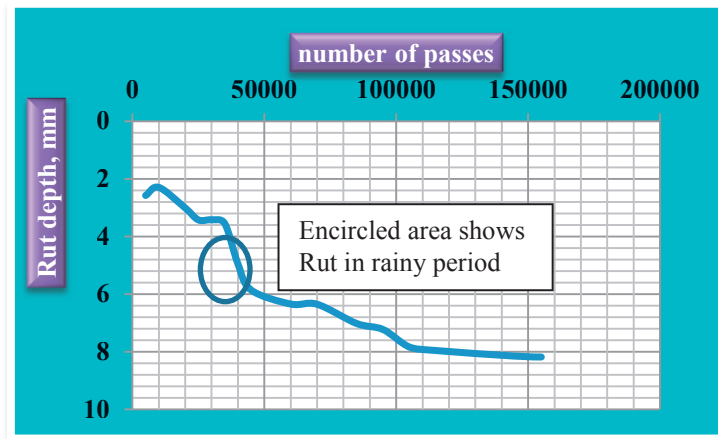


Figure 4: Rut depth with number of passes with steep slope during raining period

In the above figure 4, the progression of rut depth with number of passes is shown with the moisture condition of the pavement upto the 1, 65,000 passes only for better visibility. As, it is evident from the figure 4 the marked circular area, the rut depth between 35,000 and 40,000 passes have increased significantly as it was raining for about 50mm in the month of February during the second week. The average rut depth was taken for all the segments of the test section excluding the acceleration and deceleration zone of 1m each on either side of the test section.

The rut progression with the applied load and tyre pressure in the given variation with the temperature is shown below in Figure 5 after 2, 70,000 passes making it to 4.32 msa using fourth power law. The average rut depth after 2, 70,000 passes is about 9.24mm.

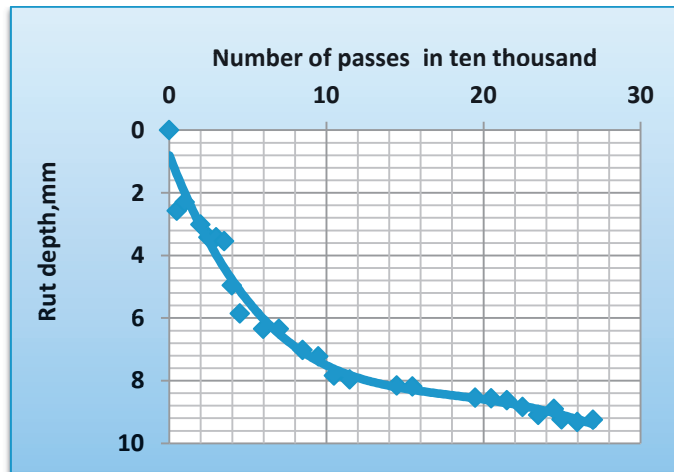


Figure 5: Rut progression with the number of passes



The best fit line for rut depth progression with increased load repetitions was drawn after trying different trend line in microsoft excel, the polynomial trend line as shown in Figure 5 was found out to be best fitting the scatter with a equation as shown below and R<sup>2</sup> value of 0.978

$$y = -2E-05x^4 + 0.0024x^3 - 0.0841x^2 + 1.2918x + 0.8128..... (3)$$

Where y and x are rut depth in mm and number of passes respectively. The intercept 0.8128 indicates that even before any load application there could be a small irregularity at the surface, which is normally allowed in the construction specifications.

### 3.1 Air Voids

Post evaluation of the test section was also done to find the reduction of air void in the pavement after the repetitive application of load on the test strip. The cores were taken from the test section from rutted as well as non rutted section to compare the change in air void content of the test section. The test to determine the air void content has been performed using automatic vacuum sealing method done as per AASHTO TP 69.

Table 3: Air voids of the Test section

Sample	Bulk Density, g/cm <sup>3</sup>	Maximum Theoretical density	Air Voids %
BC(U)	2.342	BC=2.47 %	5.26
DBM(U)	2.362		5.183
BC(NR)	2.333	DBM=2.489%	5.66
DBM(NR)	2.319		6.809

(BC=Bituminous Concrete, DBM= Dense Bituminous Concrete, U=unidirectional, NR= non rutted)

### 3.2 Rutted section

The rutted section after the known application of load, tyre pressure, and speed is shown in Figure 6.



Figure 6: Rutted section

## 4.0 Conclusions

- It can be seen from the above figures 4 and 5 that the initial average rutting found after 5,000 passes is about 2mm on the test section which is presumed to be happened due to the post compaction of layers.



- The rain has a significant effect on the performance by higher rate of increment in rutting of the test section as shown in figure 4.
- To accelerate the damage of the pavement, the wheel load and tyre pressure was increased which is evident after 4.32 msa of traffic where significant rutting has taken place as shown in figure 5.
- FWD test concludes that the average surface layer moduli (after temperature correction) is comparable to the value recommended in IRC:37-2012, as given for bituminous layer as shown in table 2.
- Change in air voids were found for BC (0.4%) and DBM (1.626%) layers when compared with normal surface (without load) and rutted section (uni-directional load after 2,70,000 passes).
- The correlation equation between progression of rutting with number of passes was found to be statically satisfactory which is  $y = -2E-05x^4 + 0.0024x^3 - 0.0841x^2 + 1.2918x + 0.8128$ , having  $R^2$  value of 0.978.

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